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AMES RESEARCH CENTER

SYSTEM ENGINEERING REPORT

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Prep.by Scott S. Maa

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Alternate # _____

SUBJECT

CAVITY AND TELESCOPE THERMAL MODEL

PROJECT : SOFIA

DISTRIBUTION.: SOFIA LIBRARY

Project: SOFIA
Subject: Cavity and Telescope
            Thermal Model

Report No: SSM029
Date: July 27, 1992
By: Scott Maa

A thermal model for the SOFIA cavity and telescope has been generated using computer programs TRASYS (Thermal Radiation Analyzer System) and SINDA (System Improved Numerical Differencing Analyzer). TRASYS was used to generate radiation couplings among the nodes and the absorbed heat fluxes from the earth. The results of the TRASYS run and other inputs (thermal mass, conduction, and convection) are used in SINDA to solve for steady state and transient temperature distributions.

The model is based on the phase B design produced by Zeiss, Dornier, and Man, except the insulation thickness and cooling air flow for the Nasmyth tube are increased (this is necessary in order to meet the temperature requirements).

Fig. 1 shows the model generated by TRASYS. The cavity was simulated by a cylinder of 350 cm radius and 440 cm length. A 75° section of the cylindrical wall is open to the ambient atmosphere. The cavity opening is partially covered by a 88 cm strip which represents the shear layer control ramp. Although Fig. 1 shows the Nasmyth tube and air bearing, these items were deleted in the TRASYS run because they extend beyond the cavity envelope and tend to produce erroneous results.

Other assumptions are listed below:
1. Cavity air recovery temperature is 233 °K.
2. Sky temperature (for radiation calculation) is 132.8 °K.
3. Earth radiation is 242.9 w/m^2 with no reflected sunshine.
4. Cabin air temperature is 294.4 °K.
5. Air bearing mounting frame is stainless steel (phase B report did not specify material).
6. Insulation thickness (cm):

Bulkhead cavity side	10
Tracker & acq. cameras, gyro.	2
Nasmyth tube interior	3 (phase B design: 1cm)
Nasmyth tube exterior	0

7. Nasmyth tube cooling air flow rate is 1.5 kg/s. (phase B design: 1 kg/s)

Material properties are as follows:
1. Specific heat in w-hr/kg/k

CFRP	.233
Aluminum	.244
Zerodur	.228
Invar	.128
Stainless steel	.128

2. Thermal conductivity in w/cm/k

CFRP	.28 in fiber plane, .013 perpend. to fiber
Aluminum	1.49
Zerodur	.0164
Invar	.107
Stainless steel	.156

Insulation   .0004
3. Emissivity
         Mirror surface   0.05
         All other surfaces   0.9
         To simplify analysis, diffuse reflection is assumed for all surfaces.

Heat sources in watts:
         Secondary mirror   74
         Tracker camera   50
         Acquisition camera   50
         Gyroscope   67
         Air bearing supply air   0 (assume same temp. as cavity air)

For convection heat transfer, the flow in the cavity is assumed to be turbulent, with velocities of 15 m/s, 10 m/s, and 5 m/s for upper, middle, and lower sections of the cavity respectively. Natural convection only is assumed for areas between primary mirror and mirror cell, air bearing and support frame, and surfaces on the cabin side.

The model consists of approximately 280 nodes with node number breakdown as follows:

1	sky
2	cavity air
3	cabin air
4	heat leak through bulkheads
5	heat leak through air bearing
6	heat leak through Nasmyth tube
11-24, 31-34	cavity wall surfaces
25-28, 35-38	cabin wall surfaces
41	cavity floor
91-118	telescope barrel inside, above primary mirror
121-128	telescope barrel inside, below primary mirror
130-149	center piece outside (vertical)
150-159	center piece top
160-169	center piece bottom
171-184	center piece aft end
201-218	primary mirror
221-268	primary mirror cell
271-273	tertiary mirror and support
274	secondary mirror assembly
281-313	spiders
320-324	Nasmyth connection tube
331-340	Nasmyth tube
341-361	air bearing and supports
371-380	Nasmyth tube insulation surface
381-391	Nasmyth tube cooling air
400,401	acquisition camera (400) and skin (401)
410,411	tracker camera (410) and skin (411)
420,421	gyroscope (420) and skin (421)
1001-1112	thermal junction nodes

Temperatures are given in degrees K, heat flow in watts.

Fig. 2 shows the steady state results, it indicates that except for the secondary mirror, the design meets the SOFIA specifications. Temperature ranges for various components are listed below:
         Cavity walls   229.2 °K   -   234.7 °K

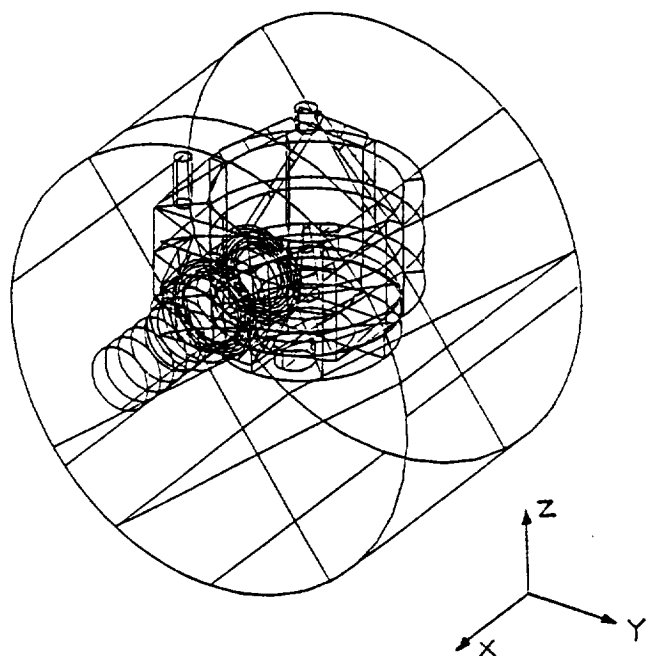|		
Telescope barrel inside	229.6	- 233.0
Center piece	227.4	- 236.7
Primary mirror	232.7	- 233.0
PM cell	230.8	- 235.3
Secondary mirror assembly	236.8	
Tertiary mirror & supports	229.6	- 230.1
Spiders	230.2	- 231.2
Nasmyth tube	236.5	- 284.9
Nasmyth connection tube	234.2	- 237.1
Nas tube inside surface *	233.0	- 234.8
Air bearing & supports	249.8	- 262.8
Cameras & gyro	250.3	- 272.9

* considered the same as the cooling air temperature.

Heat leaks through the bulkheads, air bearing, and Nasmyth tube are
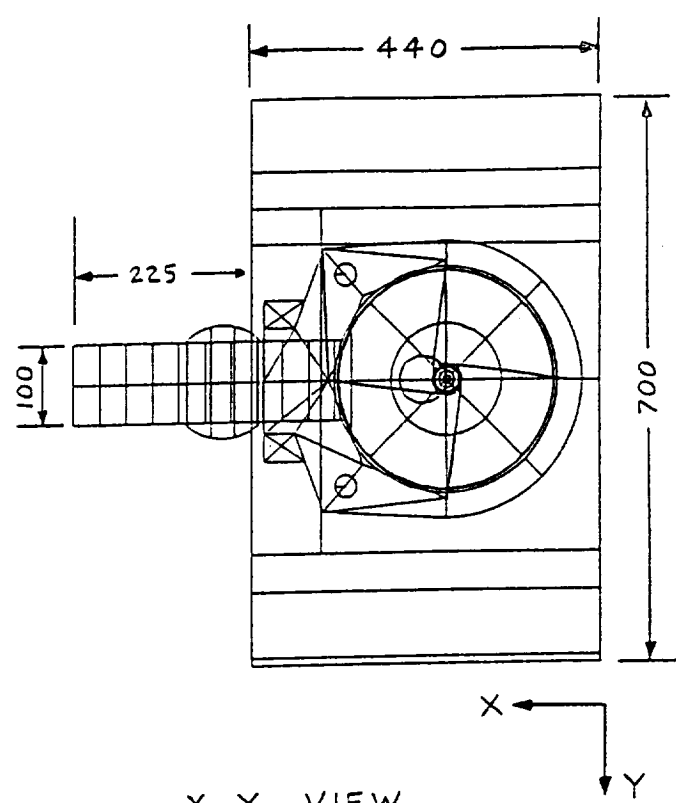1760 w, 112 w, and 353 w respectively.

Fig. 3-5 show transient results. For the transient run, it is assumed that the SOFIA telescope was initially cooled down to 243 °K and then subjected to a flight cavity environment of 233 °K. The results show that the primary mirror cools down slowly, with time constant greater than 3 hr, while the center piece and telescope barrel cool down rapidly, with time constants less than 0.5 hr. Primary mirror cell, secondary mirror, Nasmyth tube, and air bearing all have fairly large time constants.
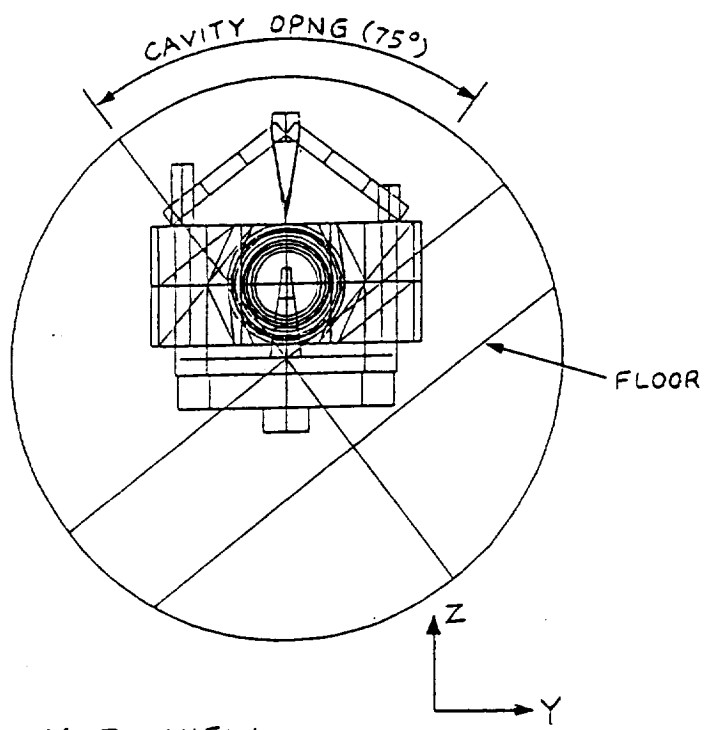
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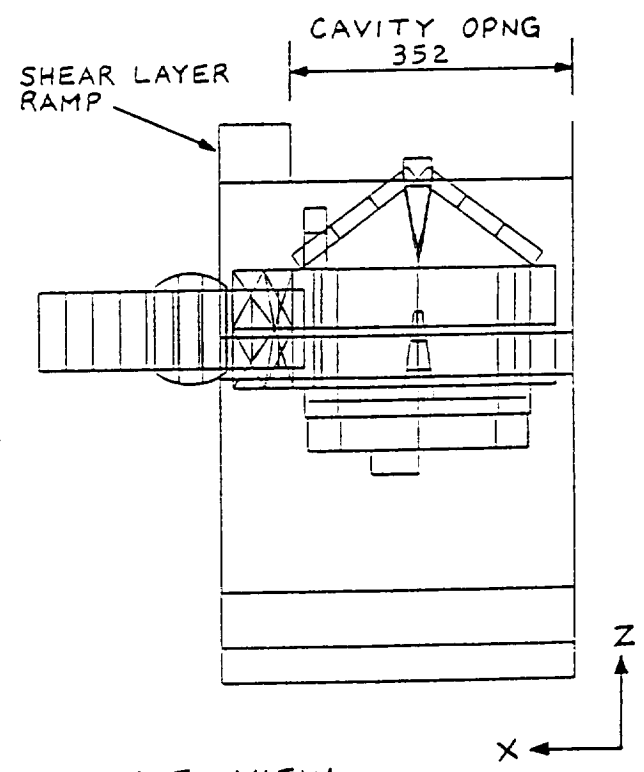|	
✓ G. Thorley	T041-3
J. Hirata	T041-3
C. Wiltsee	T041-3
D. Machak	T041-3
S. Hubbard	244-10
G. Sarver	244-14
L. Chang	244-14
E. Dunham	245-6

440

225

100

700

Z

X

Y

3 D PLOT

X-Y VIEW

CAVITY OPNG (75°)

FLOOR

Z

Y

Y-Z VIEW

CAVITY OPNG
352

SHEAR LAYER
RAMP

Z

X

X-Z VIEW

FIG.I SOFIA THERMAL MODEL

ALL DIM.
IN CM

Node	T	Node	T	Node	T	Node	T	Node	T	Node	T
41=	232.37	91=	232.18	92=	232.35	93=	232.74	94=	232.20	95=	231.16
96=	230.61	97=	230.39	101=	230.11	108=	230.11	102=	229.72	107=	229.76
103=	229.69	106=	229.83	104=	230.19	105=	230.29	111=	230.74	118=	230.82
112=	229.55	117=	229.87	113=	229.69	116=	229.86	114=	229.75	115=	229.87
121=	232.96	122=	231.75	123=	231.77	124=	232.87	125=	232.84	126=	232.78
127=	232.76	128=	232.92	130=	232.46	139=	232.22	131=	232.61	138=	232.74
132=	232.50	137=	232.20	133=	232.04	136=	232.15	134=	232.19	135=	232.28
140=	232.48	149=	232.81	141=	232.95	148=	232.84	142=	232.73	147=	232.46
143=	232.28	146=	232.54	144=	232.66	145=	232.67	150=	230.15	159=	230.17
151=	229.78	158=	229.98	152=	228.25	157=	227.95	153=	227.83	154=	227.93
155=	228.04	156=	227.41	160=	233.18	169=	233.19	161=	232.93	168=	232.85
162=	232.34	167=	232.81	163=	232.36	164=	232.70	165=	232.82	166=	232.81
171=	236.68	172=	235.28	173=	234.32	174=	233.63	181=	232.18	182=	232.33
183=	232.63	184=	232.40	201=	232.76	202=	232.66	203=	232.69	204=	232.71
205=	232.73	206=	232.75	207=	232.78	208=	232.77	211=	233.08	212=	232.85
213=	232.77	214=	232.75	215=	232.76	216=	232.79	217=	232.83	218=	232.91
221=	232.91	222=	232.48	223=	232.59	224=	232.67	225=	232.73	226=	232.84
227=	232.86	228=	232.91	231=	234.00	232=	233.08	233=	232.86	234=	232.83
235=	232.85	236=	232.90	237=	233.02	238=	233.32	241=	232.94	242=	232.50
243=	232.68	244=	232.57	245=	232.67	246=	232.88	247=	232.90	248=	232.95
251=	235.29	252=	233.18	253=	232.91	254=	232.86	255=	232.90	256=	232.96
257=	233.14	258=	233.62	261=	233.04	262=	230.83	263=	231.20	264=	232.96
265=	232.85	266=	232.74	267=	232.79	268=	233.07	271=	230.08	272=	229.84
273=	229.61	274=	236.82	281=	230.33	282=	230.55	283=	231.15	291=	230.77
292=	230.52	293=	230.81	301=	230.24	302=	230.18	303=	230.60	311=	230.65
312=	230.65	313=	230.98	320=	234.21	321=	235.20	322=	236.73	323=	237.13
331=	236.51	332=	238.52	333=	241.61	334=	248.15	335=	255.54	336=	263.64
337=	275.63	338=	281.30	339=	283.87	340=	284.85	341=	249.84	342=	256.03
343=	262.81	351=	251.70	352=	256.99	353=	262.80	361=	262.72	400=	250.27
410=	255.73	420=	272.94	13=	233.20	14=	232.98	15=	232.06	16=	229.18
11=	231.33	12=	233.12	22=	231.48	23=	234.13	24=	234.68	25=	291.18
17=	230.04	21=	234.49	28=	291.19	31=	233.17	32=	234.60	33=	234.67
26=	291.01	27=	291.16	36=	291.18	37=	291.18	38=	291.16	371=	232.63
34=	234.24	35=	291.10	374=	236.28	375=	237.05	376=	237.85	377=	239.05
372=	235.24	373=	235.57	380=	239.27	381=	234.66	382=	234.69	383=	234.81
378=	239.46	379=	239.46	386=	234.65	387=	234.50	388=	234.30	389=	234.02
384=	234.78	385=	234.74	401=	233.24	411=	233.95	421=	236.95	1001=	231.20
390=	233.70	391=	233.35	1004=	230.58	1005=	230.67	1006=	230.53	1007=	230.33
1002=	230.27	1003=	230.38	1012=	231.53	1013=	231.66	1014=	232.25	1015=	232.31
1008=	231.24	1011=	232.45	1018=	232.43	1021=	232.71	1022=	231.90	1023=	231.50
1016=	232.28	1017=	232.21	1026=	231.66	1027=	231.71	1028=	232.74	1031=	232.64
1024=	231.69	1025=	231.76	1034=	231.05	1035=	231.14	1036=	231.08	1037=	230.84
1032=	230.90	1033=	230.93	1042=	232.57	1043=	234.97	1044=	233.94	1045=	235.19
1038=	232.66	1041=	233.66	1048=	232.51	1051=	229.92	1052=	229.75	1053=	229.91
1046=	234.04	1047=	234.98	1103=	231.86	1104=	232.83	1105=	232.81	1106=	232.79
1101=	232.97	1102=	231.70	1111=	233.13	1112=	237.71				
1107=	232.80	1108=	232.96								
1=	132.80	2=	233.00	3=	294.40	4=	1760.4	5=	111.69	6=	352.88

FIG. 2 SOFIA Steady State Temperatures

FIG. 3   SOFIA TELESCOPE TRANSIENT TEMPERATURE
          MIRRORS, TELESCOPE BARREL
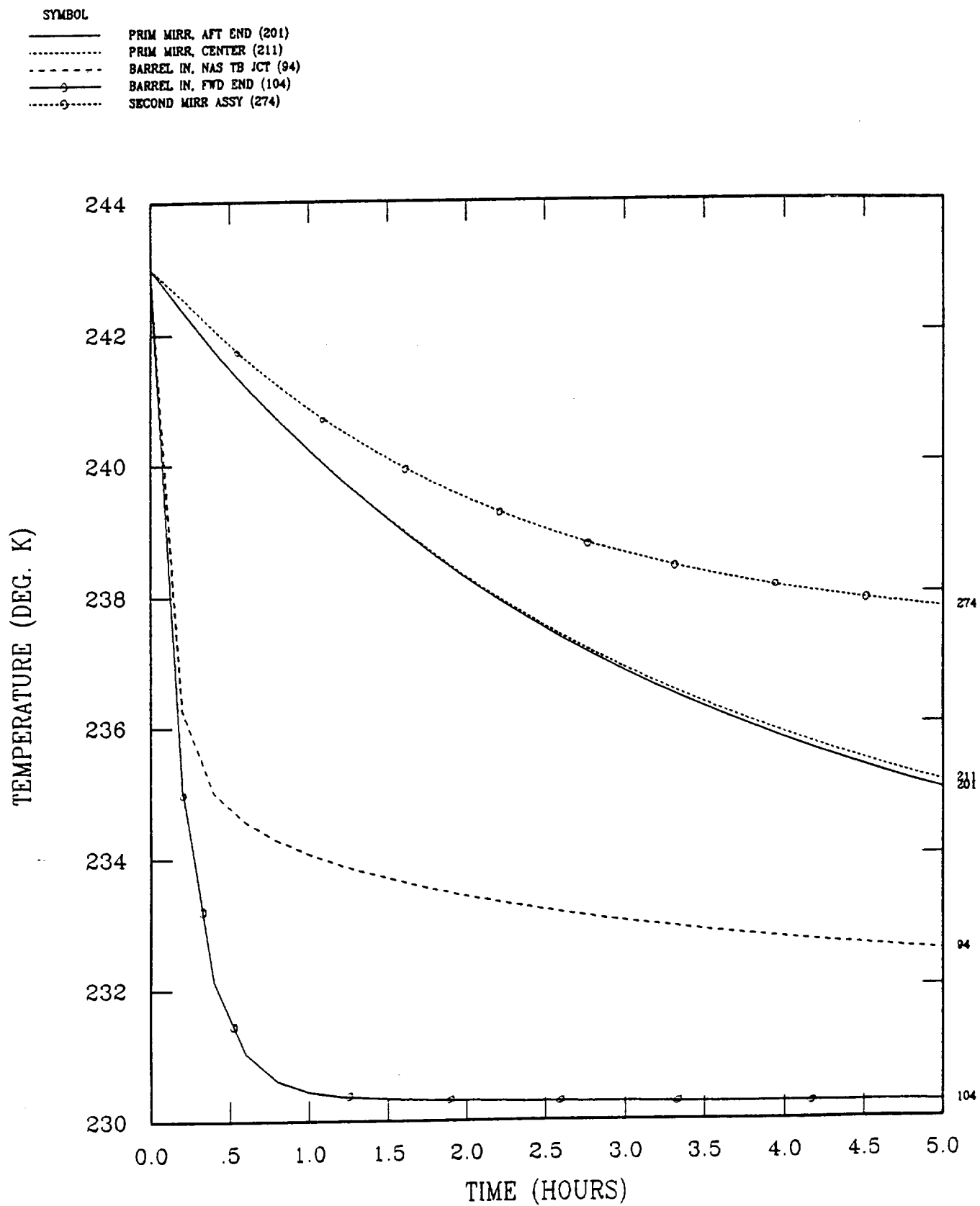
FIG. 4   SOFIA TELESCOPE TRANSIENT TEMPERATURE
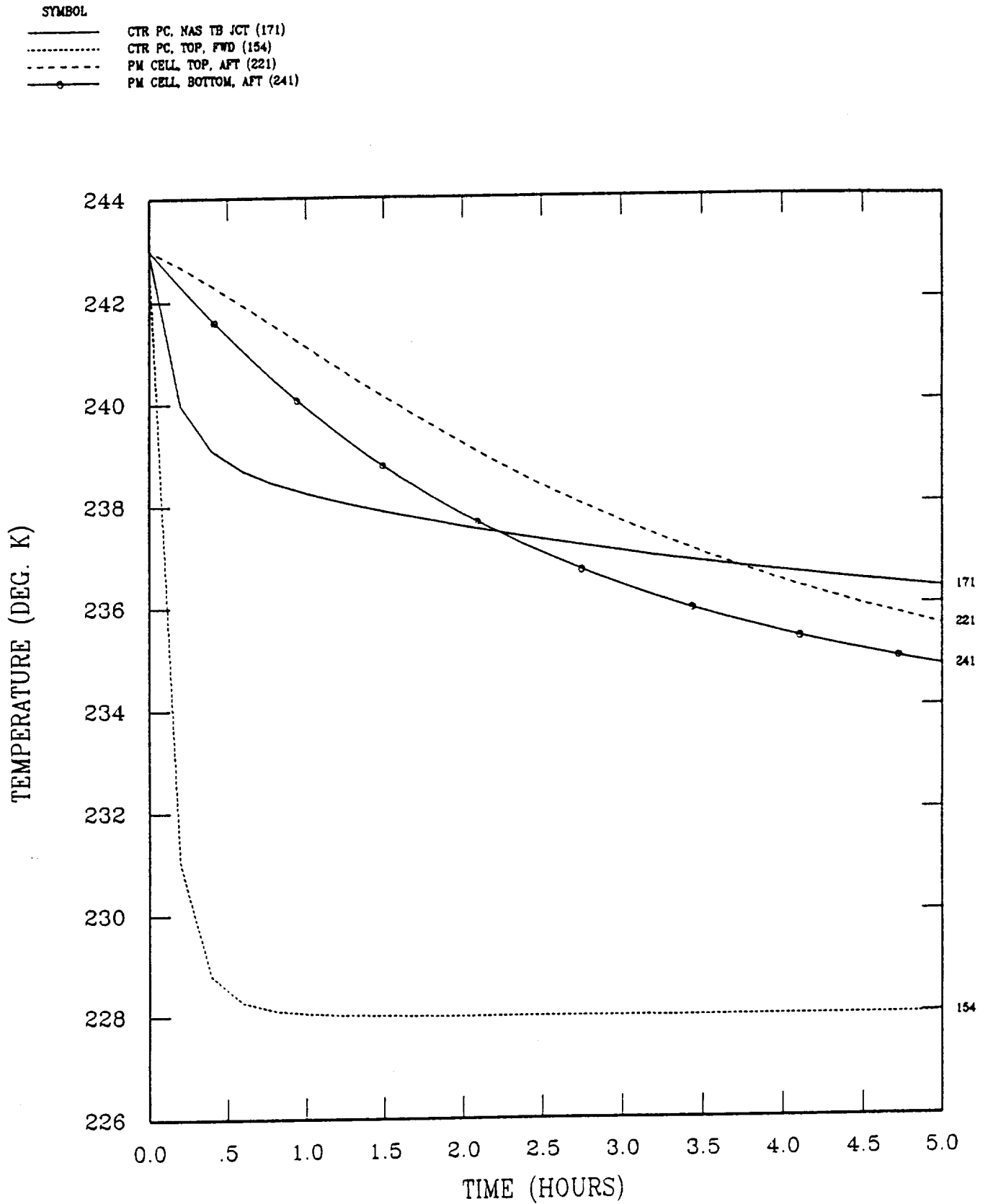   CENTER PIECE, PM CELL

FIG. 5   SOFIA TRANSIENT TEMPERATURE
            NASMYTH TUBE, AIR BEARING

SYMBOL
—————— NAS TB CAVITY END (331)
.... NAS TB CABIN END (340)
— — — — AIR BEARING FWD (341)
——o—— AIR BEARING AFT (343)